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Program Area of Interest: Fuel Transformer Solid Oxide Fuel Cell

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Abstract

The following report documents the technical approach and conclusions made by Acumentrics Corporation during latest budget period toward the development of a low cost 10kW tubular SOFC power system. The present program, guided under direction from the National Energy Technology Laboratory of the US DOE, is a nine-year cost shared Cooperative Agreement totaling close to \$74M funded both by the US DOE as well as Acumentrics Corporation and its partners. The latest budget period ran from July of 2005 through December 2005. Work focused on cell technology enhancements as well as BOP and power electronics improvements and overall system design. Significant progress was made in increasing cell power enhancements as well as decreasing material cost in a drive to meet the SECA cost targets. The following report documents these accomplishments in detail as well as the layout plans for further progress in next budget period.

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Table 1: SECA Phase I generator

Table 2: SECA Phase I generator

INTRODUCTION

Acumentrics Corporation has focused during the latest six-month budget period of the SECA program on the design and manufacture of micro-tubular SOFC power systems approaching twice the power density now achieved from state of the art anode supported tubular designs. By developing a common stack design with high power density cells capable of meeting the SECA cost targets, a number of markets will be opened to this technology. Present markets being focused upon include telecommunication, remote residential and military markets. Operation on fuels including natural gas and propane will be developed for the telecommunication and remote residential markets. These fuels will be developed and demonstrated during Phase I of the program. Operation on liquid fuels, including diesel and JP-8, will be developed for the military markets. These fuels will be developed and demonstrated during Phases II and III of the program.

The overall goals of Phase I of the program, which represents three years of development, include:

1. Design of a common low cost generator to meet all chosen markets.
2. Development of an anode supported micro-tubular cell capable of twice the power density presently achieved.
3. Prototype testing of a natural gas or propane fueled unit meeting and exceeding SECA goals.

Research and development to achieve the above goals can be listed in three major sub-tasks:

1. **System development and integration** – In this task work is focused on the functionality and cost reduction of major BOP components. Thermal hydraulic components are being developed and tested as well as the necessary control strategies. Power electronics and control hardware is being refined and cost reduced to meet the goals of the program. Work is also concentrating on thermal recovery and burner designs for stationary and mobile applications.
2. **Cell Technology Development** – In this task work is focusing on improvements in cell power density through material changes and refinements. Composition and morphology of the anode, electrolyte, and cathode are all being addressed to increase cell power.
3. **Stack Technology Development** – In this task work is focused on generator design and assembly to reduce cost and improve reliability. Connections to the anode and cathode for current collection are being optimized. Casting of insulation to net shape or near net shape is also a focal point for cost reduction.

EXECUTIVE SUMMARY

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Task 1.0 - System Development and Integration

Subtask 1.1 – Prototype Stationary System Design

The changes made to the stack interconnect wiring and isolators to prevent current leakage through the porous alumina silicate material were incorporated into the generator CAD model. Detailed drawings of the new parts were produced and the Bill of Material updated.

Subtask 1.2 – Prototype APU System Design

No work to report this period.

Subtask 1.3 - Control Strategy Development

Improvements have been made in the control software to improve the reliability of reactor ignition sequencing and to stabilize the output controls and optimize the battery state-of-charge.

Additional state variables have been introduced to the control system in order to implement a predictive shutoff of the burner as the system approaches thermal balance. At the present time this is based on the DC output current of the fuel cell.

Changes to optimize the fuel cell output control algorithms (that were made prior to the new control system being implemented) have been modified for compatibility with the new operating system. These changes improved both the stability and responsiveness of the fuel cell to load changes.

Commenced optimizations related to automated start-up and increasing output to full power. Added a “Thermal Balance Control” including automated burner shutoff and allowing the operator manual control of the primary air blower, and the heat-exchanger bypass valve.

Reactor ignition sequencing has been improved to increase the reliability of the ignition control and detection algorithms on propane fuel as well as natural gas. This has reduced the need for operator intervention during start-up of the reactor.

Further improvements to the “Thermal Balance Control” include allowing the operator manual control of the primary air blower, and the heat-exchanger bypass valve. The heat exchanger bypass valve allows some cathode air to bypass the heat exchanger, providing cooler air to the distribution plenum at the base of the stacks. Bypassing the heat exchanger allows for a more rapid shutdown, but may also be necessary at extremely

high load. The primary air blower provides premix air to the burner assembly, as well as cooling air to the igniter and stacks. Due to the premix air requirement for combustion, the primary air blower can only be overridden when the burner is off. Stack cooling air is automatically regulated by a downstream rotary ball valve, so can account for operator changes to the primary air blower.

Measurement of individual cell-voltages must account for the influence of high levels of common-mode voltage (50+ V) on relatively low differential voltages (0.5-1.0 V). This is accomplished by measuring the common-mode voltage directly and applying a correction into the software. During the past reporting period, the software algorithms have been modified to improve the rejection of common-mode voltage offsets from ± 200 mV to ± 5 mV.

Operation of the state-machine for thermal control currently requires the modification of many parameters. These parameters have previously been directly memory-mapped from the monitoring PC software, which requires the updating of this memory map whenever the software is modified. Re-mapping has been further complicated with the migration this year to a new DSP, the compiler for which frequently re-orders variables to optimize memory access/paging. This manual reconfiguration has been obviated by developing an extensible structure for the collection of parameters related to the thermal control state machine and this structure has been directly mapped through the communication protocol. As such, the compiler is restricted to moving these variables as a block, and this move is directly accounted for by the communication protocol.

Subtask 1.4 – Heat Recovery

Modifications to the recuperator test stand were completed and several test runs were made with one of the original folded sheet recuperators in place.

The folded sheet recuperator with additional air side baffles was received from the manufacturer. An inlet plenum was fabricated and installed to facilitate testing in the recuperator test stand. The figure below shows the recuperator configuration.

Several tests with this recuperator were made to evaluate the performance of the unit. At the design flowrate of approximately 1000 lpm the average effectiveness was 0.73. Although an improvement compared to the non-baffled configuration, the effectiveness is still substantially below the design goal of >80%. Discussions have been initiated with the manufacturer to determine further methods to enhance the performance of the design.

A second smaller recuperator was also received and tested. This recuperator was designed for the equivalent of a 1 kW system. The size was chosen to help in the

evaluation of aspect ratio on the performance of the recuperators. Figure 1 on the next page gives the dimensions of the unit. As seen in the drawing, the unit was fitted with an air jacket to provide additional air preheat and to minimize insulation requirements.

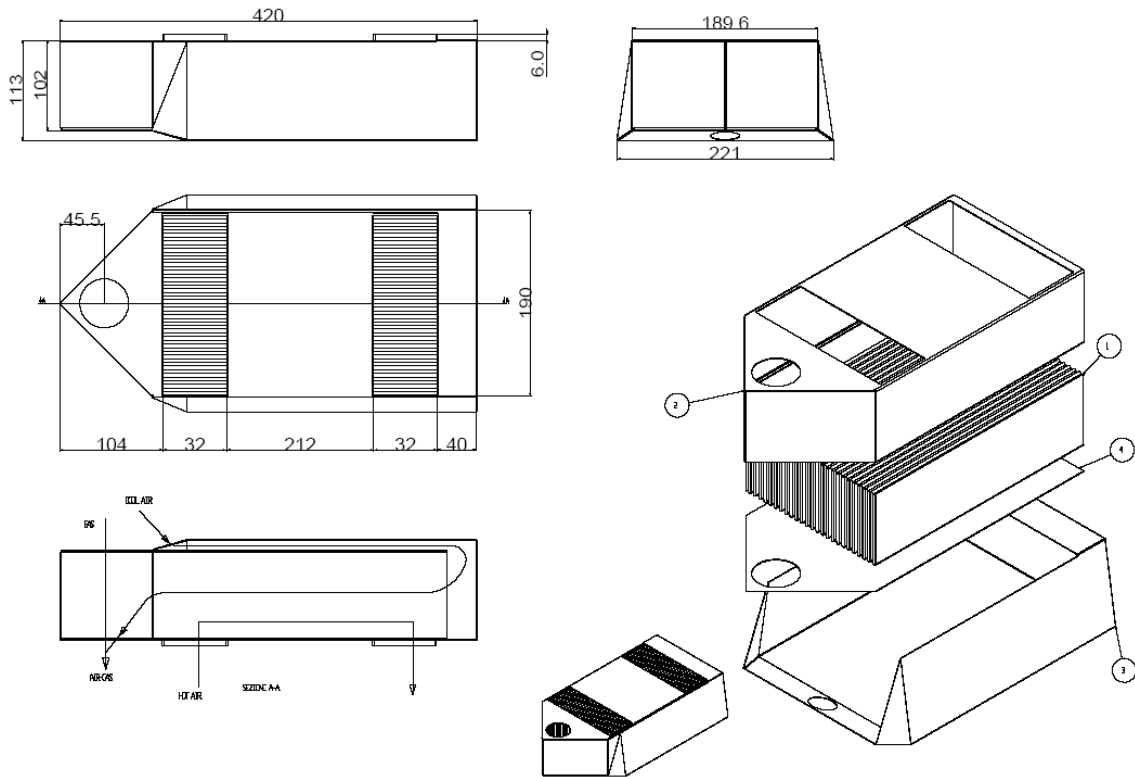


Figure 1: 1 kW Folded Sheet Recuperator (dimensions in mm)

Preliminary performance mapping was conducted.

Subtask 1.5 – Burner Design

Adjustments were made on the nozzle port sizes on the recuperator test stand burner to permit higher thermal inputs to the furnace chamber.

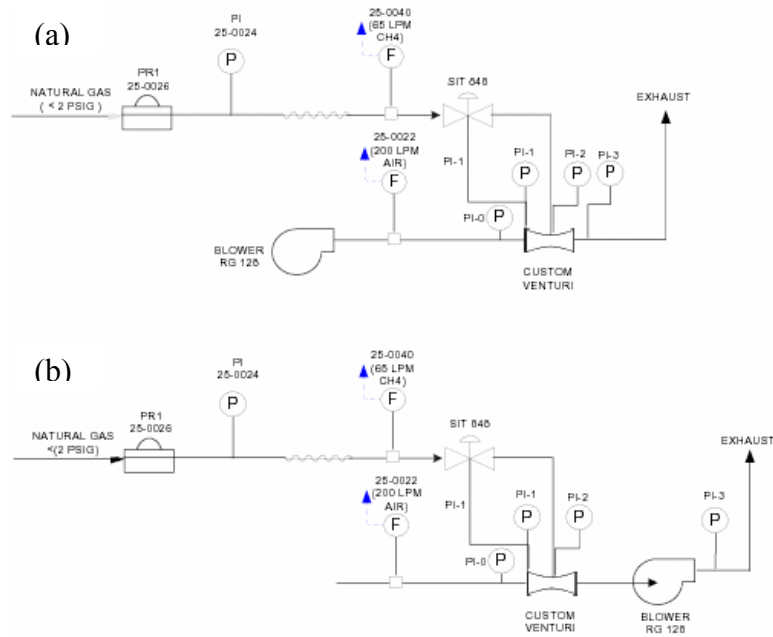
Burner operating hours have continued to be accumulated on bundle testers, stack testers and the prototype generator.

Subtask 1.6 - Gas Utilities

Premix gas burners have been used for a number of years on a broad range of heating equipment. These burners use a blower/venturi/valve arrangement to couple the fuel and air supply, so that a constant air-fuel ratio is maintained over the operating range of the equipment. Systems currently used are designed for complete combustion of natural gas and propane, with 5-50% excess air to ensure clean combustion. Work has been initiated to determine if this type of system can be utilized for control and metering of the anode air/gas stream. This low cost arrangement would be applicable for 100% partial oxidation generators and as startup and shutdown systems for generators designed for steam reformation.

Initial work uses a gas valve, a blower and custom venturi, sized for fuel flow rates of 2-8 LPM. These flow rates are suitable for startup and shutdown conditions of a steam reformed generator or the equivalent of 1 kW POX machine. If reliable operation at these low flows can be demonstrated, it is believed scale-up to larger flows will be easily achieved since combustion system thermal inputs of 5 to 50 kW are typically realized with these components.

To achieve the correct pressure conditions at the lower flow rates, a custom venturi was designed and manufactured. The venturi was sized such that at a desired maximum airflow, the venturi would deliver the required pressure differential at PI-1 (zero adjustment/ offset). The sizing of the fuel injector scales the fuel flow over the range of the offset adjustment.



Schematic 1: Flow schematic for Venturi on blower outlet (a) & Venturi on blower inlet (b)

Summary

Venturi on blower outlet:

- The custom venturi and performed to the required specification
 - Fuel flow rate 2.8-7.5 LPM
 - Air flow rate 8.5-22.5 LPM
- The system maintains an O: C 1.2 ± 0.1 within the given air: fuel flow rates
 - Confirmed with GC analysis
- The system could operate on natural gas at supplies pressures
- The flow measurement readings were very noisy

Venturi on blower inlet:

- The performance of the venturi on the inlet of the blower was comparable to that when installed on the blower outlet, flowing to atmospheric pressure
- It was determined that the high noise observed in the flow measurements was a coupling effect between the offset regulator controlling the fuel input relative to air flow. A dampener was used on PI-1 to improve metering of the fuel-air mix
- Better performance, can operate on higher outlet pressures (independent of venturi – relies on blower performance)

- Assumed improved air-fuel mixing as reported for premix combustion blower systems.

Subtask 1.7 - DC/AC Inversion

The objective of this phase of the program is to demonstrate a prototype low voltage high current inverter system capable of operating from both a battery and an Acumentrics Solid Oxide Fuel Cell (SOFC) generator. The inverter should demonstrate efficiency greater than 94% from the dc source to the inverter output prior to the isolation transformer.

Prototype Inverter System

A schematic of the prototype inverter system is shown in Figure 2. A picture of the actual hardware is shown in Photo 1. The system was designed to provide a 230 VRMS 60 Hz split phase output with a power output of 5KW steady state from either of two low voltage dc sources: a 40 VDC to 90 VDC source (SOFC input) and a 44 VDC to 62 VDC (battery input). There are two independent dual inverter assemblies providing a total of four low voltage ac outputs at 2.5KW steady state per output. Each inverter's output passes through a filter assembly to remove the PWM ripple component. Note that the inverter packaging as implemented was not optimized for volumetric efficiency rather for ease of assembly and better access to the individual components and sub-assemblies during testing.

The individual components within the system are as follows:

Power Electronics:

The inverter is based on the Acumentrics Fuel Cell Interface Converter (FCIC). This assembly was designed as a bi-directional buck-boost dc/dc converter that would convert the load-dependent SOFC output voltage (with a range of 40 VDC to 90 VDC) into a fixed dc output voltage to both charge the storage / peak shaving batteries and provide a fixed dc input for the inverters used in current SOFC generators.

Modifications to the FCIC assembly were required for it to function as a dual H-bridge inverter. The 75 Volt MOSFETs and bus capacitors were replaced with 100 Volt parts to accommodate the higher bus voltage. Filter inductors normally mounted on the FCIC assembly were removed and replaced with AC busbar assemblies. The inverter ac outputs were cabled over to the filter assemblies. The two dc input sources were connected to each inverter assembly via the input busbar assemblies at the top and bottom of each inverter assembly.

Output Filter:

The filter inductor consists of two legs with three 40 μ H in parallel per leg for a total inductance of 26.7 μ H. The capacitor consists of two paralleled 40 μ F polypropylene film capacitors for a total capacitance of 80 μ F. The cutoff frequency for the filter is 3446Hz. Note that the filter assembly was designed to generate the required 26 VRMS transformer primary voltage from a dc bus voltage up to 150 VDC thus had to accommodate substantial ripple current. This led to inductors larger than needed for the current SOFC voltage range but provides flexibility for future development should SOFC output voltage increase beyond the current range.

Each of the four filter assemblies has a Hall Effect current sensor at the output of the upper inductor leg. This provides high bandwidth phase current feedback for the current control loop.

Step Up Transformer:

The step up transformer converts the inverter output voltage, regulated at 26 VRMS, to the required 115 VRMS output. There are two transformers, each with two isolated primary secondary windings. Each of the four primaries is driven by one of the inverter / filter assemblies. The secondaries are connected such that the required 230 VRMS split phase output is generated. Note that the secondaries can be reconfigured to provide a single higher power 115 VRMS output as well as a single 230 VRMS 50 Hz output with no change on the inverter / primary connections and minor changes in the control firmware.

Controller:

The control board is an Acumentrics design based on the Texas Instruments DSP. It was designed to provide independent voltage and current control for up to six H-bridge PWM amplifiers. This will support single-phase, split-phase, and three-phase SOFC / battery applications.

DC source input current sensors:

Current sensors are used to measure dc input current from both dc sources.

TCIP interface module:

This provides a connection between the PC-resident HMI program and the DSP controller. This provides HMI capability to allow user to control the inverter and monitor system parameters

Efficiency

The PZ4000 power meter has four channels so it was decided to take efficiency measurements from one dc source; through one dual-inverter assembly; then to the driven transformer output.

The dc bus was set to 50 VDC for all tests. This represents the approximate full load SOFC output voltage as well as the nominal battery voltage.

The efficiency as measured by the PZ4000 power meter. The PWM frequency was set to 30KHz for this test. Note that the inverter efficiency goal of 94% has been met (bridge efficiency, yellow trace) at output power up to 3400 Watts.

Typical inverter output where the inverter was driving a 3KW load. The distortion present in the output current is due to the transformer, the exact source is unknown and the distortion wasn't present when the inverters drove a low voltage high power resistive load. The output voltage (channels 1-3) shows no distortion and negligible PWM ripple.

Note the inverter efficiency improves as switching frequency decreases but not by a significant amount (typically 0.5%). This leads to the conclusion that inverter losses are dominated by conduction losses.

Transformer losses vary by 0.1% - 0.2% as switching frequency increases, thus the increased ripple content passing through to the transformer has little impact on its losses. This suggests that the PWM frequency can be decreased to improve its efficiency with an acceptable increase in transformer losses due to increased PWM ripple current.

Figure 3 shows output waveforms for two inverters driving both primaries of one transformer from two separate dc sources (both nominally at 50 VDC). This demonstrates the ability of the inverter to source power from both the SOFC generator and the battery pack into a common load.

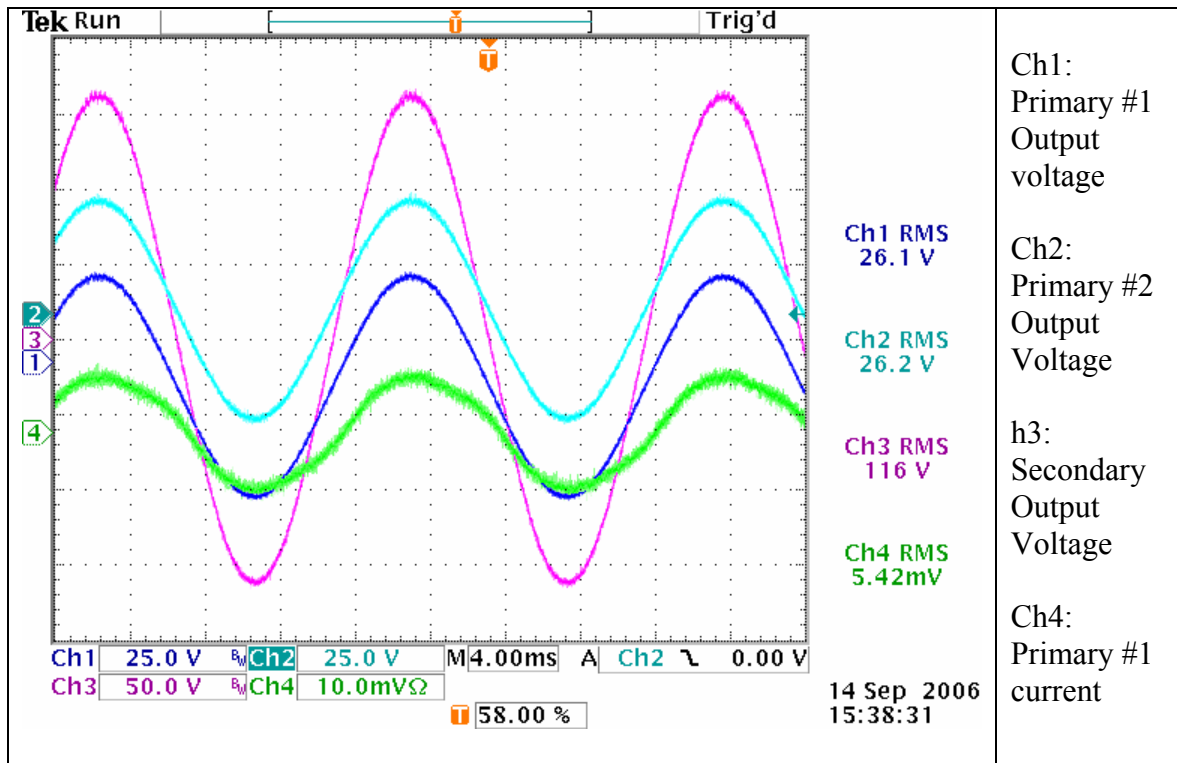


Figure 3: Inverter Output, two different dc sources

Conclusion

- The inverter efficiency goal has been met.
- The feasibility of a low voltage / high current dc/ac inverter has been demonstrated.
- The single stage conversion approach has been successfully demonstrated. This both reduces cost and improves overall efficiency relative to current two-stage conversion approach, where the first stage converts the widely varying SOFC output voltage to the fixed dc input for the OEM inverters currently implemented.
- Inverter losses are dominated by MOSFET conduction losses. Design of low voltage / high current inverters should optimize for this when efficiency is the primary objective.

Subtask 1.8

No work to report this period.

Task 2.0 – Cell Technology Development

Subtask 2.1

Performed Isolated Brazing on 3 Green ISP Cells for a Manifold Test. These cells were too large to be brazed with standard tabs. A foil was used instead; this foil was approximately 135 mm in length, 10 mm tall and 1.4 grams in mass.

Subtask 2.2

A number of experiments have taken place during the last 6 months involving the application of a GDC interlayer onto Acumentrics anode base tube with a view to producing a cell with improved performance. It is considered that a GDC interlayer between the anode and YSZ electrolyte will provide increased triple phase activity due to the mixed ionic electronic conductivity of GDC.

To this end, GDC slurry was formulated and applied by vacuum infiltration for differing time intervals to Acumentrics base anode tube in the green state. The tube was then bisque fired in the usual way before application through vacuum infiltration of the usual YSZ layer. This was followed by a sintering step utilizing a top temperature of 1500°C. The photos below show that the applied GDC layer delaminated in all but one of the sintered tubes shown on the next page.



Photo 2: GDC layer delaminated

In an attempt to circumvent this delamination issue, three further tubes, D360154, 157 and 162, were prepared and vacuum infiltrated from the bisque fired state using the same

methodology as the tubes above but different dip times. All three tubes again showed delamination after sintering; though the coating on tube 157 showed the least delamination, see the photo below.



Photo 3: GDC layer delaminated

In Summary

For the GDC particle size utilized in the above investigation, variation of the tube state and dipping time did not result in a stable GDC coating on Acumentrics tubes. Further experimentation utilizing different GDC or SDC grades will take place to try to lay down a viable interlayer on Acumentrics tubes.

Subtask 2.3

No work to report this period.

Subtask 2.4

No work to report this period.

Task 3.0 Stack Test Development

Subtask 3.1 – Cathode Current Collector Improvements

No work to report this period.

Subtask 3.2 – Anode/Cathode Current Collection

Sintered Bundle

A method and apparatus to allow the bundle of cells to be assembled was designed. It consisted of a single row tube sheet (four holes) that had the ability to hold together four cells (one complete row).

The four cells in question were laid out on the table and the tube sheet is placed over the outlet caps. The outlet caps were then aligned with a rod passing through the slot in the end of the cap. This guaranteed that the cell series connections would line up and connect with the adjacent cell. This meant that the outlet caps had a preferred orientation when cemented in place on the cells.

With the introduction of the sintered bundle concept, a number of new components and assembly ideas must be developed. One of the critical parts is a cell-to-cell series connection. With manufacturability at the forefront, a simple design is essential. The connector must provide a connection from the cathode braids to the chromite band of the adjacent cell. Given the right design, the connector could also provide some measure of structural stability to the bundle after assembly.

A number of concepts were designed and evaluated. They all consisted of mica sheet and expandable insulation parts in various geometries.

The final design was chosen so that the cathode braid winding method would not have to change at the Cell Manufacture level. A layer of mica was placed between the cathode layers, over the chromite band. This ensured that the cathode braid could not touch the chromite band causing a cell short-circuit. The cathode braids were then formed into a square-wave shape. Another layer of mica (with central hole) was then placed over the braids and a cube of expandable insulation was passed under the braid and over the mica layers, securing the components together.

Once the outlet caps had been aligned and the alignment rod was in position, the inlet ends of the cells were brought together, thus contacting the series connections along the length of the cell. On each of the series connections a thin layer of silver paste was applied to ensure a well-adhered connection.

When the inlet caps were the desired distance apart, the tube sheet was inserted over the four cells, completing the fixturing.

Another fixture was set up at each end of the cells, which consisted of a compression device for compressing the rows of cells together. The rows of cells were placed one on top of the other and the top of the compression fixture and brought to bear down on the top row. This contacted the remaining series connections, and the bundle was formed.

One final fixture was required to allow the compression fixture to be removed while keeping the bundle in compression. A tube sheet was inserted over the edge vertical cells at each end, keeping the desired cell spacing.

After removal of the compression fixture, the bundle was placed into an electric furnace and heated to sinter the series connections together. During sintering purge gas was delivered to the inside of the cells to prohibit oxidation of the anode. Inspection of the cathode to anode series connections after removal from the furnace revealed that a solid connection was established.

This formed a relatively stable connection and this geometry was used to assemble a sixteen-cell bundle to prove out the concept.

The bundle was conditioned for approximately 8.5 hours including a thermal cycle before V-j and fuel utilization sensitivity data was collected. The bundle exhibited a steady rise in power during the conditioning period and the current was increased, in increments, to a maximum of 29 amps. V-j readings were taken on the way down, decreasing the load to 6 amps.

Subtask 3.3 - Generator Design

Work continued on developing concepts related to cathode air flow delivery and extraction methods for vertically oriented stacks utilizing sintered bundle configurations as well as the presently used fused braid interconnect method. Both through manifold and radial injection air delivery methods were detailed.

Stack Interconnects and Power Leads

In order to electrically connect the stacks together, the cell braids of the top and bottom cells of adjacent stacks must be joined together. For the outboard stacks (#1 and 4), the cell braids must be connected to the power. For the connections between stacks 1 & 2 and stacks 3 & 4, which are at the tops of the stacks, these connections were supported on

mica strips resting on the cells. The braids penetrating through these strips ensure that the mica cannot move during shipping.

At the bottom of the stacks, Stack #1 cathode lead, Stack 2 & 3 interconnect and Stack 4 anode lead, a machineable alumina-silicate material was utilized to capture the braids and to ensure that there was no shorting to the cpox tube below. The insulating block, as shown in the figures below, rests on the cpox tubes and the combination of capturing tabs machined into the alumina and the wires within the trough ensure that the blocks cannot move out of place during shipping.

A design concept was developed for delivering the offgas collected in the manifold offgas chamber into the downcomer without the need for additional collection and distribution piping. The arrangement is suited for single stack, vertical configurations with radial air injection. As shown in the model below, the offgas enters the downcomer through the base via offgas injector tubes, which extend up into the downcomer. This will provide sufficient residence time for the gases to be oxidized prior to enter the fuel cell stack. The downcomer is situated directly over the end plate of the fuel plenum; the end plate has internal passages to collect and deliver the offgas to the injector tubes.

Subtask 3.4 – Manifold and Cap Development

In the continuing development of isolated brazing, an 8-cell run was performed to see how the thermal characteristics (with respect to cells per run) change the quality and repeatability of a successful isolated braze joint. The results were very promising; all 8 cells were electrically isolated. Six cells had a high resistance reading while the two remaining cells had a resistance of 19Kohms and 0.5Mohms. Of the 8 cells brazed only one failure occurred for leak rate of 251torr/min, about 4x desired levels.

The next step in isolated brazing involves changing the cup from nickel to stainless steel to help reduce costs. Several experiments have been attempted with little resolve. The first isolated braze using a stainless steel cup failed because the braze material rolled to the back of the cup and ran over the cup edge. The most noticeable feature of this run was that the front of the cup heated more rapidly than the rest of the cup. This run was repeated with another stainless steel cup with the same results. The brazing experiment went well with the cell being electrically isolated and leak tight. The only noticeable differences in the cup run were the uniformity of heating around the cup and the temperature or redness of the cell during brazing.

In the next braze experiment the power ratings were adjusted from 50% to 65% for a more gradual heating of the cell to ensure that it was hot enough to fuse with the braze material. This run was similar to the first attempt, but took approximately 5 minutes longer to ensure the cell became red before the braze material melted. The front of the cup remained the hottest point, and after the braze melted it once again ran to the back of the cup and over the edge. It appeared the braze material was acting as a heat sink; the

absence of braze material in places caused the cup to become white hot and melt only one portion of the tab.

In the final experiment conducted, the braze tab gap was aligned so that it would not directly face the coil. The cup edge lacking the material still turned white before the rest of the cup, and the braze run was stopped. After allowing the cell to cool, the run was restarted to attempt to elicit a more uniform heating. The cell heated more evenly. At 65% power and minutes into the run the tab did not melt, but appeared deformed. The power was then increased to 70% and finally 75% but the material did not melt. The material stayed on the rear-facing area between the cup and cell.

Additional work will explore the possibility of changes to cover gas flow rates and power-time effects on the heating with the different stainless steels.

Task 4.0 Fabrication and Processing Technology Development

Subtask 4.1

No work to report this period.

Subtask 4.2

No work to report this period.

Subtask 4.3

No work to report this period.

Task 5.0 Fuel Processing Technology Development

Subtask 5.1

Carbon Deposition:

A third experiment has been completed in an all inconel assembly. An O/C ratio of 1.4 was used (*cf* previous trials with O/C=1.15 and 1.2), and in agreement with the theory that the deposition is correlated to the carbon activity, significant carbon deposition took much longer to occur. In this instance, no carbon plug was formed at the flange but carbon seemed to uniformly coat most of the tubing. Photo 22 looks into the tubes from the high temperature flange sides. Significant fouling is seen in both inconel tubes.

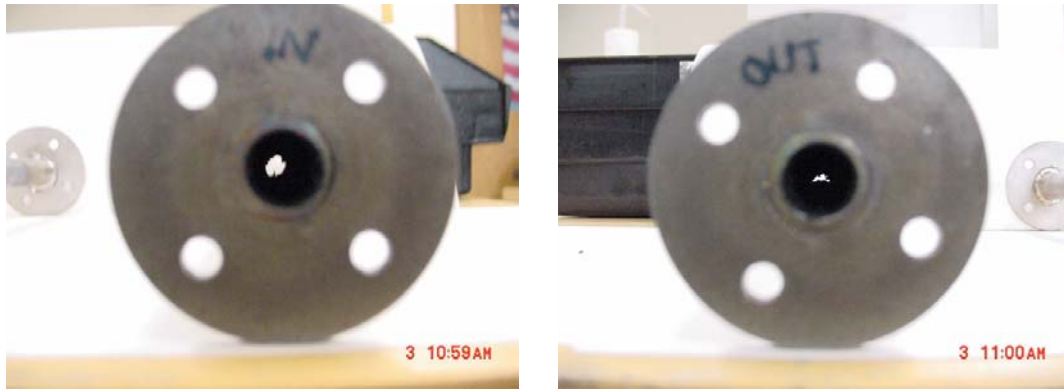


Photo 4: Carbon fouling of inconel tube

The experiment has resumed with new inconel tubing but with at $O/C = 1.2$ and a temperature of 650°C .

The fourth experiment in this series has been completed. At an O/C ratio of 1.2, but a flange temperature of 650°C , carbon deposition was suspected to have started occurring after ~ 300 hours. This result is still consistent with the theory that deposition is correlated to the carbon activity.

The fifth experiment in this series continues. Carbon deposition at $O/C=1.2$, $T=600^{\circ}\text{C}$ in inconel tubing is studied after a pre-treatment of the specimen. The sample ran for 476 hours without any indication of a pressure increase (indicating carbon buildup). For the amount of operational hours compared to previous experiments, it seems as though the carbon build up is much less than those experiments previous.

Subtask 5.2

The diesel reformer was completed and trials have started using the S-8 fuel obtained from Wright-Patterson AFB. A flow of 2ml/min S8 was completely converted into wet Syngas at a steam/carbon ratio of 4. The measured outlet composition (dry basis) agreed with equilibrium predictions, based on the empirical S-8 composition of $\text{C}_{11.3}\text{H}_{24.5}$ (Figure 4). The diesel reformer performance will be mapped out followed by its an integration with a fuel cell bundle. Note that to operate a 48 cell bundle at $150\text{mA}/\text{cm}^2$ requires reforming $2.44\text{g}/\text{min}$ of S-8 at $S/C=4$.

Species	Mole%	
	meas.	equil.
CH ₄	0.0%	0.0%
H ₂	71.6%	69.9%
H ₂ O	3.0%	3.0%
CO	12.9%	13.6%
CO ₂	12.5%	13.5%

The reformer was modified for long-term operation. It has been run continuously for periods up to 3 days to test for stability and operation of the units. A pump failed after the 3-day test when starting again and is out for repair. Nonetheless, the unit appears to be stable for relatively long periods of time, allowing the start of the integration with a bundle test.

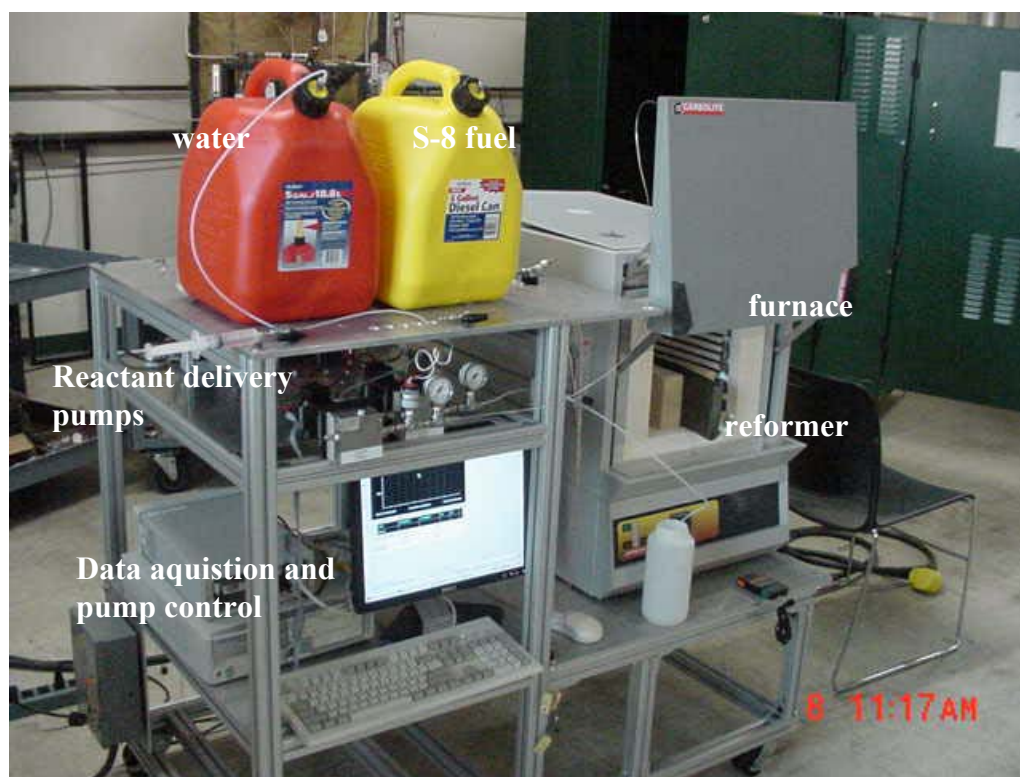
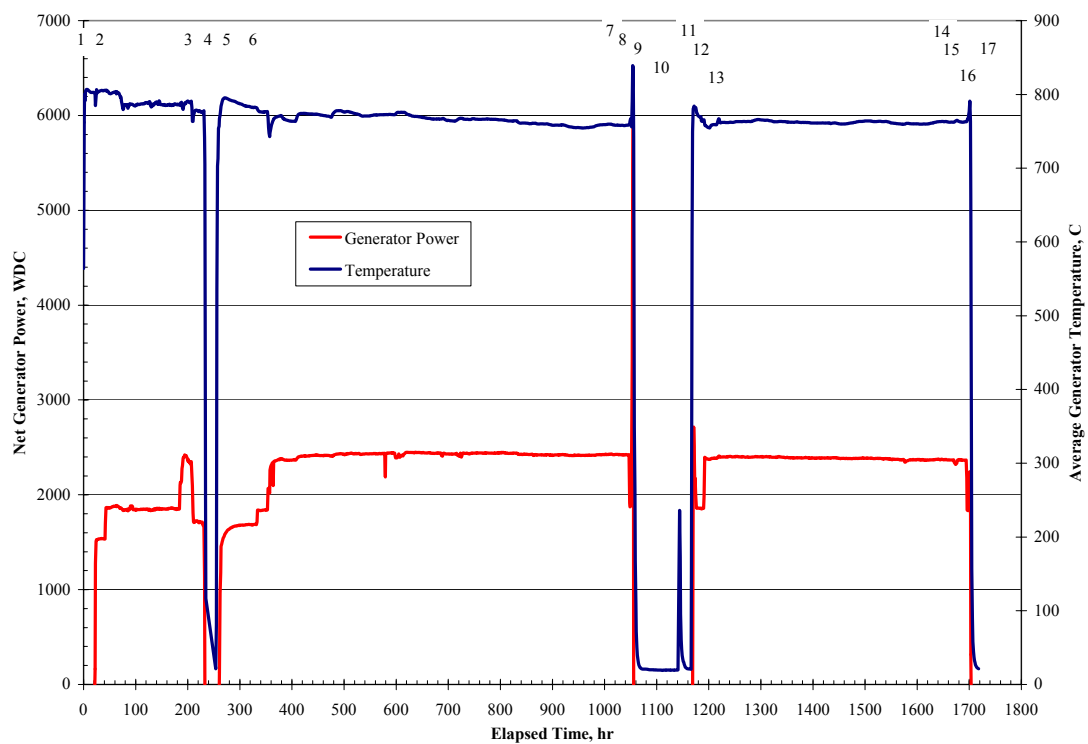


Photo 5: Diesel reformer test set-up progress

Task 6.0 System Design

Subtask 6.1

The SECA Phase I generator unit has completed its trials this month, and shown to successfully pass all DOE criterion laid out in the SECA Phase I contract. Additional details are found in the final report, submitted three days ahead of schedule, as well as the cost report. This graph of the unit is shown below with a table of the labeled points showing the events that occurred and when:



Graph 2

Table 7:

Point #	Date	Elapsed hours	Event/Notes
1	6/27/06 16:19	0	Startup- burner fired to begin heating of stack
2	6/28/06 14:31	45	Power drawn from Stack
3	7/6/06 22:49	220	High Efficiency point taken (1hr)
4	7/7/06 8:50	232	Generator cooled for repair of short
5	7/8/06 18:00	266	Generator started p and hits 1500WDC net output
6	7/11/06 22:49	342	Degradation point #1 taken
7	8/10/06 09:44	1037	1000hrs completed
8	8/10/06 09:44	1037	Degradation point #2 taken
9	8/10/06 14:53	1054	Peak Power Measured
10	8/10/06 16:09	1055	Begin 1 st Thermal cycle to room temperature
11	8/15/06 07:36	1167	Heat back up from thermal cycle, begin nine power cycles
12	8/16/06 06:30	1190	Degradation Point #3
13	8/16/06 08:06	1192	Begin 500hrs NOC run
14	9/6/06 11:24	1699	End 500hr NOC run, begin degradation point #4
15	9/6/06 13:52	1701	Begin High Efficiency Point #2
16	9/6/06 15:36	1703	Shutdown
17	9/7/06 06:46	1718	Data ends

Overall, the unit showed excellent performance, and the resulting variables from the analysis are listed in the table below:

Table 8:

Parameter	Value obtained	Uncertainty (k=2, 95% confidence interval)
<i>High Efficiency Point 1</i>	35.7%	1.3%
<i>High Efficiency Point 2</i>	36.9%	1.3%
<i>Peak Power</i>	6119W	22W
<i>Degradation Rate</i>	-0.5%/500hr	$\chi^2_v = 29$
<i>Thermal cycle degradation</i>	0.75%	0.49%
<i>Availability</i>	97.8%	N/A
<i>Cost</i>	\$685/kW	N/A

The report detailing the results of the cost study was also submitted, along with the audit of that study. Currently, the status of the audit of the generator run is the only outstanding item required for continuation of success in Phase II of the SECA program.

Subtask 6.2

No work to report this period.

List of Acronyms and Abbreviations

AC	Alternating Current
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BOM	Bill of Material
BOP	Balance Of Plant
CAD	Computer Aided Design
CAN	Controller Area Network
CM	Common Mode
CPOX	Catalytic Partial Oxidation
DC	Direct Current
DSP	Digital Signal Processor
DTA	Differential Thermal Analysis
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMC	ElectroMagnetic Compatibility
ESTOP	Emergency Stop
FCIC	Fuel Cell Interface Converter
FCS	Fuel Cell Stack
FCUPS	Fuel Cell Uninterruptible Power Supply interface
FET	Field Effect Transistor
FU	Fuel Utilization
GUM	Gas Utility Module
HMI	Human-Machine Interface
IC	Investment Casting
I/O	Input / Output
IR	InfraRed
LED	Light Emitting Diode
lpm	Liters per minute
MIM	Metal Injection Molding
mlpm	Milliliters per minute

List of Acronyms and Abbreviations Continued

MOR	Modulus of Rupture
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NPT	National Pipe Thread
NYSERDA	New York State Energy Research and Development Authority
PC	Personal Computer
PCB	Printed Circuit Board
P&ID	Piping and Instrumentation Diagram
PID	Proportional Integral Differential
POX	Partial Oxidation
PLC	Programmable Logic Controller
PWM	Pulse Width Modulation
ROM	Read Only Memory
RPM	Revolutions per Minute
RPTS	Rapid Prototype Test Station
SEM	Scanning Electron Microscope
SiC	Silicon Carbide
SOFC	Solid Oxide Fuel Cell
SPI	Serial Peripheral Interface
TEC	Thermal Expansion Coefficient
TGA	Thermal Gravimetric Analysis
UPS	Uninterruptible Power Supply
TI	Texas Instruments
w.c.	Inches water column
YSZ	Yttria Stabilized Zirconia